UNIVERSITY OF CENTRAL OKLAHOMA

Edmond, Oklahoma

Jackson College of Graduate Studies

Planning and Carrying out Investigations in Science Education

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

In partial fulfillment of the requirements

For the degree of

MASTER OF SCIENCE IN BIOLOGY

By

Cheyenne S. Heath

Spring 2020

Planning and Carrying out Investigations in Science Education

Planning and Carrying out Investigations in Science Education

Planning and Carrying out Investigations in Science Education

Thesis Title

Cheyenne Heath

Author's Name

April 30, 2020

Date

Jackson College of Graduate Studies at the University of Central Oklahoma

A THESIS APPROVED FOR

THE DEPARTMENT OF BIOLOGY

By

Elizabeth Allan Digitally signed by Elizabeth Allan Date: 2020.05.04 08:55:50 -05'00'

Committee Chairperson

Mike Nelson Digitally signed by Mike Nelson Date: 2020.05.04 10:22:36 -05'00'

Committee Member

James Creecy Digitally signed by James Creecy Date: 2020.05.04 08:57:23 -05'00'

Committee Member

Committee Member

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to those who inspired me and cheered me on throughout my academic career. I would like to first thank Dr. Elizabeth Allan, Professor of Biology from the University of Central Oklahoma for her guidance and support through both my undergraduate and graduate degree programs. She continually inspires me as a scientist, as a teacher, as a friend, and as a person. She provided opportunities to me and opened doors for me by sharing her time and expertise.

I would like to thank Dr. Mike Nelson, Professor of Educational Sciences, Foundations, and Research from the University of Central Oklahoma for his direction through my educational research.

I would also like to thank Dr. James Creecy and Dr. David Bass, Professors of Biology from the University of Central Oklahoma, for contributing to my research, leading me, guiding me, and teaching me the skills of a scientist. Without their willingness to help me, this project would not have been possible.

Lastly, I must thank my parents for instilling in me at a young age the value of education. I am grateful to be surrounded by people who believe in me and help me grow personally and professionally. I will always be grateful.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT OF THESIS

University of Central Oklahoma

Edmond, Oklahoma

NAME:

Cheyenne Searcy Heath

TITLE OF THESIS:

Planning and Carrying out Investigations in Science Education

DIRECTOR OF THESIS:

Dr. Elizabeth Allan, Department of Biology

PAGES: 43

ABSTRACT:

Due to the dual nature of this thesis project, the abstract, like the rest of the thesis, will be presented in two parts. The first section will outline a perspectives article that summarizes biological research conducted at the University of Central Oklahoma. The second section will describe education action research that was designed and conducted

in an Oklahoma ninth-grade science classroom following the conclusion of the biological research.

Chapter 1: A Call for Scientists to Put Their Science into Action Abstract

While most of the public still holds science in high regard, a growing level of distrust between the general public and science has been illuminated through modern issues such as climate change, evolution, vaccinations, and recent disease pandemics. Scientific distrust is a multifaceted issue, but some mistrust results from the public having a fundamental misunderstanding of science due to its complexity or due to poor communication by the scientific community. The importance of modern science comes from the ways that science can be used to better society, so those who conduct scientific research have a responsibility to share the results of their work with the general public and with public policymakers so that society can reap the benefits of science as efficiently as possible with the least amount of controversy.

Keywords: science communication, science and public audiences, science and society.

Chapter 2: Assessing the Effect of Planning and Carrying out Investigations upon Student

Recent changes in science education consider the way students learn and process scientific information. The practice of planning and carrying out investigations is fundamental to students' understanding of science because planning and carrying out investigations integrates many other science and engineering practices. Science education research shows that providing students with opportunities to engage in the scientific practices of scientists and engineers creates a deeper understanding of science for students, however, the research is lacking to determine whether or not this effect carries over to student content knowledge and perceptions of science. To better understand this relationship, I conducted a study of a curriculum designed to use the practice of planning and carrying out investigations to increase student content knowledge and measure student attitudes toward science. My study looked at 55 high school freshmen, aged 14-16 who were taught science curriculum through a total of three control and three experimental (treatment) units during the spring semester. This study used quantitative analysis of science content pre-test and post-test scores and an attitudes-towards-science survey to create data for analysis. Findings indicate that developing and implementing a curriculum that emphasizes planning and carrying out scientific investigations has no

statistically significant positive or negative effect on student content knowledge growth ($p = 0.264$) or student attitudes toward science ($p = 0.178$) as compared to a traditional curriculum. There is evidence that the treatment contributed to student learning, just not necessarily more than traditional methods of teaching. Future research should assess changes in students' capacity to scientifically reason as a result of curriculum changes using instruments separate from those that measure content knowledge. Future research should also assess what long term effects of the implementation of a curriculum that focuses on scientific investigation has on content knowledge growth and students' attitudes towards science.

Keywords: classroom investigations, secondary science, perceptions of science, and Next Generation Science Standards

PROJECT INTRODUCTION

Research shows that good, effective, K-12 science education involves providing students with authentic learning experiences that allow students to engage in the "doing" of science in the same way scientists and engineers would (NRC 2012). Despite decades of recommendations to involve learners in scientific activities that model authentic science, K–12 teachers still struggle to integrate scientific practices in their classrooms. One reason for this struggle is inexperience (Capps and Crawford 2013). The undergraduate college experiences and academic backgrounds of many K-12 science teachers are different from that of career scientists and engineers (Sadler et. al 2010).

Like many K-12 science educators, the time spent earning my undergraduate degree and teaching certification was split between science content and education courses. Much like my graduate program, my undergraduate degree program consisted of two parts: Science and education. The science portion of my undergraduate degree consisted of various levels of chemistry, biology, and physics. I chose a degree in general science education, so I admittedly chose breadth over depth. I chose a degree that was specifically geared towards being able to teach multiple content areas within a high school setting. Separately I took courses that taught me about the psychology of students, how to write units and tests, and how to manage a classroom. Through classroom observations and student teaching I learned the skills needed to be a high school teacher which, in essence, amounted to undergraduate research, just not in the hard sciences. I learned very well how classrooms worked, how schools worked, and how students learned, however, that left me with little time to conduct undergraduate research in the hard sciences.

For both parts of my degree I was fortunate to take courses from professors who were experts in their fields and highly respected in the scientific community. These professors modeled quality teaching skills and showed me the importance of effectively communicating science, however, at no point in my undergraduate work did I conduct my own scientific research. I took a variety of lab classes, but these labs were different from an undergraduate research experience. These labs were counterparts to lectures and were a chance for me to reinforce the content I had learned from lectures. I sometimes use labs like this in my classroom because I believe they have a beneficial place, however, these types of labs are fundamentally different from conducting your own research. As a new teacher I knew my content very well, but I struggled to implement the "doing" of science or the practices of science into my classroom.

The vast majority of my college science education came from lectures and textbooks, yet I was expected to enter a high school classroom and teach students how science *really* works. I felt unprepared. I could name hundreds of scientists. I could describe their famous experiments and regurgitate their findings in chronological order, but what I did not fully understand and could therefore not fully teach was the process of how those findings came to be. I felt like I had never truly participated in the scientific enterprise, even though I had a bachelor's degree in science education. I needed to increase my scientific credibility and increase my understanding of science as a discipline so that I could turn around and more successfully teach science skills to high school students.

As part of my master's program and thesis, I, for the first time, conducted biological research with the help of Dr. James Creecy and Dr. David Bass. It was an eyeopening experience when Dr. Creecy told me Dr. Bass had brought 10 culture tubes back from the Grand Cayman Islands and we needed to identify them. Before Dr. Creecy helped me with the procedures and steps, I remember thinking “but how? What do I do?” I wanted there to be a pre-printed manual of easy to follow steps that would take me from start to finish there wasn’t. Luckily, I was working with advisors who took the time to point me in the right direction and guided me through the proper techniques so that I could successfully plan out an investigation to identify the samples. I then realized this is how science works in the real world: a problem is presented, and it’s up to researchers to not only find the solution but to conduct literary research, write the steps to find the solution, and communicate their results. The story and results of this study can be found in the perspective article *A Call for Scientists to Put Their Science into Action* that follows.

This was the first time I was asked to engage in scientific research not to reinforce content, but to increase my understanding of science as a whole, and by doing so, I became a better science teacher. After going through that process, I was much more capable of implementing authentic science experiences in my classroom, such as providing high school students with opportunities to plan and carry out their own engineering investigations.

The second part of my Master’s program and thesis involved using the practices and skills I learned in the science lab in my classroom. I conducted a study of a curriculum designed to use the practice of planning and carrying out investigations to increase student content knowledge and measure student attitudes toward science. This study is described in the scientific article *Assessing the Effect of Planning and Carrying* *out Investigations upon Student Content Knowledge and Perception of Science in a High School Science Classroom* that follows.

Through this study I presented my students with authentic opportunities to "think like a scientist". My students became frustrated and confused just like I did when they were asked to not only go on a search for a solution, but to write the steps to find that solution. Had I not had the experience I had conducting scientific research, I would have been much more likely to give in to their frustrations and give them step-by-step instructions like I had for so many groups of students before. I wanted to provide an age-appropriate opportunity for my students modeled after my research experience, and in doing so, my students had the chance to become better scientists themselves.

REFERENCES

National Research Council. 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.

Capps, D. & Crawford, B. (2013). Inquiry-based instruction and teaching about nature of science: Are they happening? *Journal of Science Teacher Education, 24*(3), 497–526. https://doi.org/10.1007/s10972-012-9314-z

Sadler, T.D., Burgin, S., McKinney, L., & Ponjuan, L. (2010). Learning science through research apprenticeships: A critical review of the literature. Journal of Research in Science Teaching, 47(3), 235-256. https://doi.org/10.1002/tea.20326

A Call for Scientists to Put Their Science into Action

Cheyenne S. Heath

University of Central Oklahoma

The relationship between science and society is growing increasingly turbulent (NASEM, 2017). While most of the public still holds science in high regard, a growing level of distrust between the general public and science has been illuminated through issues such as climate change, evolution, GMO's, vaccinations, and recent disease pandemics. Perhaps as a result of the abundance of information readily available through the internet, the public may be searching for fast, definitive answers, but the science is inconclusive or there is disagreement within the scientific community. Science-based controversies are often dependent on the cultural and social contexts of the communities they embroil. For example, information about evolution will be received differently in the southern United States compared to the northern and coastal states. While the overall relationship between science and society is positive, turbulence is often created when science conflicts with religious doctrine, long-held moral beliefs, ethical teachings, and social views, or when new science raises ethical or political questions that science itself is unable to answer (NASEM, 2017). Scientific distrust is a multifaceted issue, but some mistrust results from the public having a fundamental misunderstanding of science due to its complexity or due to poor communication by the scientific community. A skeptical public is not inherently a bad thing for scientists. Healthy levels of public skepticism can be helpful to scientists as debate can strengthen the science by challenging its claims and demanding better evidence. The ever-changing relationship between science and society places a responsibility on those who conduct scientific research to embrace an expanded role in public communication. This role involves sharing the results of their work with the general public and with public policy-makers in an effective manner to create better outcomes for science and society with the least amount of controversy (Verdier and Collins 2017).

Critical scientific research is needed for smart decision making. Now, more than ever, it is our obligation as members of the scientific community to communicate and evoke change through the results of our studies. One might argue that publishing research in the peer-reviewed literature *is* communicating science, but is it *effectively* communicating science? Most scientific literature is inaccessible to the general public due to its complexity or because it can only be found behind a paywall. Publishing in the literature is and will always be an important part of scientific research, but with a growing cultural problem of distrust in science, it is no longer enough. No longer can scientists stay isolated in their research facilities and universities only sharing their research with other scientists. We must make our results known in such a way that it makes an impact on the world around us. Science is important far beyond the scope of discovering novel organisms, phenomena, or groundbreaking evidence. Science is important because it helps ameliorate societal problems when scientists speak up to create a link between the science itself and the purpose of their science. Effectively communicating scientific results to the general public or to those in positions to influence public policy is a challenge, but who is better equipped to take on a challenge of ingenuity than scientists, technologists, and engineers?

I am a high school science teacher and graduate student. I don’t yet have advanced degrees, publications, or accolades, but I am passionate about using science to make a difference in the world around me and that requires me to communicate my scientific findings in a manner that is unconventional. As part of my graduate research advisors and I were presented with a real-world problem that had real-world consequences.

The Cayman Island Water Authority had reported that they had started to notice shrimp parts on the filters for a drinking water supply at the Lower Valley pump station near Bodden Town. This water supply was previously classified as freshwater with no significant contamination. They had never found shrimp parts or any other animal parts on filters before. They noticed a slimy substance coating and clogging the filters, another new discovery. From photographs and specimens, my advisors were able to identify two species of shrimp living in the water supply, *Borbouria cubensis* (black shrimp) and *Naushonia manningi* (lobster shrimp). Prior to the arrival of the shrimp species, the environment where water is drawn has always been anaerobic and loaded with hydrogen sulfide, so the bacteria found in the area were all anaerobic bacteria species. Without oxygen, there should have been no dominant animal species present, yet shrimp parts were showing up in the filters. The amount of oxygen present must have recently changed and we wanted to determine what effects this may have. To find some answers, my goal was to identify what types of bacteria were present in the water supply in a broad sense to determine the most likely cause of the bacterial bloom, so the information could be reported back to the Cayman Island Water Authority and the problem could be addressed.

Bacteria were collected from the water source, isolated on plates, grown in broth, and given to me. From each broth tube, DNA was extracted. The resulting DNA samples were then amplified using universal 16s primers (PRK341F/PRK806R) (Takahashi et al. 2014) and a cycle sequencing kit. Sequenced DNA was then analyzed in triplicate using a genetic sequencer and spectral analysis. Triplicate sequences were then aligned to make a consensus sequence and that sequence was used for identification using NCBI BLAST (NCBI Resource Coordinators) to determine high probability genetic matches. I was successful at obtaining sequences for three of the original 10 samples.

Table 1

Summary of results for three sequenced samples using NCBI BLAST (NCBI Resource Coordinators)

	Likely genus	**Sequence homology using NCBI BLAST**	**Aerobic or anaerobic**
Sample 1	*Vibrio*	94%	facultative anaerobes
Sample 2	*Gallaecimonas*	95-96%	strictly aerobic
Sample 3	*Vibrio*	95%	facultative anaerobes
	Stakelama	95%	strictly aerobic
	Sphingosinicella	93%	strictly aerobic
	Sphingomonas	93%	strictly aerobic

Based on NCBI BLAST (NCBI Resource Coordinators) genetic matches, sample one had a 94% sequence homology with *Vibrio*, a genus of facultative anaerobes. This means they make ATP by aerobic respiration if oxygen is present, but are also capable of switching to fermentation if oxygen is absent, so *Vibrio* species can be found in oxygen-rich and oxygen-poor environments (Madigan et al., 2005).

Sample two has a 95-96% sequence homology with *Gallaecimonas,* a genus of aerobic bacteria. *Gallaecimonas* bacteria are strictly aerobic (Zhang et al., 2018). The third identified sample was indeterminate between the following four genera: *Vibrio* (95% sequence homology), *Stakelama* (95% sequence homology), *Sphingosinicella* (93% sequence homology), and *Sphingomonas* (93% sequence homology).

It is interesting to note the presence of *Gallaecimonas* and potentially *Sphingosinicella, Sphingomonas,* and *Stakelama* in this ecosystem, as these genera are strictly aerobic (Akter et al., 2015, Huang et al. 2017). If these organisms are strictly aerobic, then they must have moved into the community after the environment became oxygenated and are a possible cause of the newly clogged filters.

Vibrio, Gallaecimonas, Stakelama, Sphingosinicella, or Sphingomonas organisms are common in aquatic ecosystems, but their proliferation is usually controlled by limited phosphate, carbon, and nitrogen (Glaeser and Kämpfer 2014, Yooseph et. al 2010, Zhang et al., 2018). It is hypothesized that this particular bloom was brought on by the introduction of a commercial nursery only a few yards away from the water supply as a result of chemical runoff from fertilizers and other agricultural byproducts traveling right through the loose, porous sediments in the area, providing an influx of phosphate, carbon, and nitrogen to this community, To be clear, this hypothesis has not been scientifically tested, but at this point, there is not a more logical explanation for the events that took place, as other research has noted that members of the Sphingomonadaceae family are chemoorganotrophic and are therefore limited by organic chemicals (Glaeser and

Kämpfer 2014). The Sphingomonadaceae family includes *Sphingomonas, Sphingosinicella, and Stakelama.* Previous studies have also determined that members of the Sphingomonadaceae family have shown to be common on clogged membrane filtration systems (Bereschenko et al 2010, Huang et. al 2008, Choi et. al 2006). Other research also notes that *Vibrio* and *Gallaecimonas* species can cause blooms as a result of increased concentrations of phosphate, carbon, and nitrogen (Yooseph et. al 2010, Zhang et al., 2018).

Admittedly, we used relatively basic genetic analysis techniques. We were not attempting to reclassify or redefine the phylogenetics of these organisms. The goal was to identify what types of bacteria were present in the water supply in a broad sense to determine the most likely cause of the bacterial bloom so that we could communicate that information back to policymakers. To accomplish this, it was not necessary to use more advanced techniques such as metagenome analysis. Our assessment was primarily based upon what was culturable, so we probably did not analyze near the amount of what was actually on the filter. Even without a complete analysis of the species present, it was clear an ecological change had taken place, and in general, human-induced changes to natural situations are not considered positive from an ecological standpoint. We suggested to authorities that they should communicate with managers of the nursery to discourage overfertilization to minimize damage to the water supply infrastructure.

A chicken farm was proposed to be built next to a different drinking water supply source, similar to the one we studied. Chicken farms produce large amounts of phosphate, carbon, and nitrogen-rich waste. Our research allowed the red flag to be put up about the problematic potential of eutrophication changing the water supply. Our data provided evidence that if the plant was implemented, the problem observed at the Lower Valley pump station would likely repeat itself. It was reported to me that ultimately, a permit was not issued to the people proposing the chicken farm, in part, based on the scientific information provided by our study.

A traditional research project identifies a hypothesis, tests the hypothesis, and communicates results; however, this type of research can sometimes fall short of enacting change. I didn’t necessarily test an established theory or demonstrate something new or novel to the field of microbiology, but that doesn’t negate the importance of the science and even more importantly, the way the science was used. I used a skill set very fundamental to the understanding of microbial ecology to effect change in an environment through policymakers that would otherwise not have had this information.

If someone like myself with no clout or titles can affect meaningful change by obtaining, evaluating, and communicating scientific information, imagine the changes that can be made by all the scientific researchers of the world with PhDs, funding, connections, and communication outlets. What point is studying all the science textbooks and reading all the peer-reviewed journals if they cannot be put into action? As members of the scientific community living in a society with a growing culture of scientific distrust, we must put science into action and make it readable and relatable to scientists and non-scientists alike.

REFERENCES

Akter, S., Du, J., Won, K., Yin, C., Kook, S., & Yi, M. (2015). Sphingosinicella cucumeris sp. nov., isolated from soil of a cucumber garden. *Antonie Van Leeuwenhoek, 108*(5), 1181-1188.

Bereschenko, L. A., Stams, A. J. M., Euverink, G. J. W. & Van Loosdrecht, M. C. M. Biofilm formation on reverse osmosis membranes is initiated and dominated by Sphingomonas spp. Appl. Environ. Microbiol. 76, 2623–2632 (2010).

Choi, H., Zhang, K., Dionysiou, D. D., Oerther, D. B. & Sorial, G. A. Effect of activated sludge properties and membrane operation conditions on fouling characteristics in membrane bioreactors. Chemosphere 63, 1699–1708 (2006).

Huang, Y., Feng, H., Lu, H., & Zeng, Y. (2017). Novel 16S rDNA primers revealed the diversity and habitats-related community structure of sphingomonads in 10 different niches. *Antonie Van Leeuwenhoek, 110*(7), 877-889.

Glaeser S.P., Kämpfer P. (2014) The Family *Sphingomonadaceae*. The Prokaryotes, 641-707

Huang, L. -N., De Wever, H. & Diels, L. Diverse and distinct bacterial communities induced biofilm fouling in membrane bioreactors operated under different conditions. Environ. Sci. Technol. 42, 8360–8366 (2008).

Madigan, Michael; Martinko, John, eds. (2005). Brock Biology of Microorganisms (11th ed.). Prentice Hall.

National Academies of Sciences, Engineering, and Medicine. 2017. *Communicating Science Effectively: A Research Agenda*. Washington, DC: The National Academies Press. https://doi.org/10.17226/23674.

NCBI Resource Coordinators. "Database resources of the National Center for Biotechnology Information." *Nucleic acids research* vol. 44,D1 (2016): D7-19. doi:10.1093/nar/gkv1290

Takahashi, S., Tomita, J., Nishioka, K., Hisada, T., & Nishijima, M. (2014). Development of a prokaryotic universal primer for simultaneous analysis of Bacteria and Archaea using next-generation sequencing. *PloS one*, *9*(8), e105592. https://doi.org/10.1371/journal.pone.0105592

Verdier, J., & Collins, S. (2017). Science Communication. *BioScience, 67*(6), 487.

Yooseph, S., Nealson, K. H., Rusch, D. B., McCrow, J. P., Dupont, C. L., Kim, M., et al. (2010). Genomic and functional adaptation in surface ocean planktonic prokaryotes. *Nature* 468, 60–66.

Zhang, Wei-Yan, Yuan, Ye, Su, Deng-Quan, He, Xiao-Ping, Han, Shuai-Bo, Epstein, Slava, Wu, Min. (2018). Gallaecimonas mangrovi sp. nov., a novel bacterium isolated from mangrove sediment. *Antonie Van Leeuwenhoek, 111*(10), 1855-1862.

Assessing the Effect of Planning and Carrying out Investigations upon Student Content Knowledge and Perception of Science in a High School Science Classroom

Cheyenne S. Heath

University of Central Oklahoma

INTRODUCTION

Few skills are more important in modern society than scientific literacy and the capacity to scientifically reason. Failure to understand the process of science and the kind of critical thinking associated with science leaves citizens unprepared to succeed in an innovative modern global economy. Being a capable member of a democracy means being able to think critically. A democracy demands that its citizens make personal, community-based, and national decisions that involve scientific information (NRC 2008). Failure to understand science equates to a failure to understand the political policies associated with technology, infrastructure, the environment, medicine, and therefore equates to an uninformed vote. Scientific knowledge allows people to think critically and ask important, productive questions. It allows us to be active participants in societal decision making as opposed to observers. A lack of scientific knowledge means relying on the unchecked expertise of others.

Despite the immense importance of developing scientific literacy and critical thinking skills, many students leave K-12 science classes without deep and meaningful scientific knowledge. Deep and meaningful scientific knowledge is a resource for becoming a critical and engaged citizen in a democracy (NRC 2008).

In the K-12 science classroom science has traditionally been taught as a disparate list of unconnected facts. Learning a list of facts is not necessarily deep scientific knowledge, as the facts are only the basis for a bigger picture. Understanding the facts and bigger pictures, the intertwined nature of the subject as a whole, and the practices of science create a deeper understanding for students and as a result, a more scientifically literate adult populace.

Many students learn science by studying textbooks or listening to lectures that summarize the conclusions of what scientists have learned over the decades. Historically, being skilled at science meant knowing various scientific definitions and being able to reiterate important discoveries of the past as accurately as possible. Classroom instruction focused heavily on what scientists know, not what they do. This approach alienates young people and as a result, many perfectly capable students leave science classrooms with fragmented knowledge feeling bored, confused, or turned off to science completely (NRC 2007). These students are underprepared to participate in a society that hinges on scientific reasoning and innovation. Recent changes in science education seeks to address this issue by considering the way students learn and process scientific information (NRC 2012).

In 2005 the National Research Council published *How Students Learn: Science in the Classroom*. This publication is the basis of our modern science education frameworks and national standards. *How Students Learn: Science in the Classroom* explains how people learn any form of new information and explains what this means specifically for science education. *How Students Learn: Science in the Classroom* claims students learn science based on the following principles: 1) Students bring preconceptions of everyday phenomena into classrooms, whether they are scientifically accurate or not. Students do not enter classrooms as blank slates. 2) To fully understand science, students must know the scientific process, or what it means to “do” science. 3) Students best learn science through a metacognitive approach (NRC 2005). A metacognitive approach teaches critical thinking through questioning and creates reflective and critical learners.

A 2007 National Research Council publication, *Taking Science to School*, stressed the importance of understanding the nature and development of scientific knowledge as a connection between the principles outlined in *How Students Learn: Science in the Classroom*. Teaching in this innovative way allows students to build functional frameworks for their growing scientific knowledge bases. *Taking Science to School* also suggests that most science curriculums are attempting to teach too many disconnected topics and new standards should be made to stress a smaller number of core science ideas. These standards should outline specific, coherent goals for curriculum and practices organized around core ideas.

In 2008, the National Research Council published *Ready, Set, Science!* This publication built upon the ideas presented in *How Students Learn: Science in the Classroom* and *Taking Science to School*. Building upon the idea that children bring prior knowledge and conceptions into the classroom, the research depicted in *Ready, Set, Science!* demanded that educators rethink young children's capacity for scientific understanding. New research indicates that children are much more capable of scientific reasoning and thought than we previously believed, and children's new understandings are built upon prior knowledge and experiences (NRC 2008). Instead of presenting science education as three principles, *Ready, Set, Science!* depicts science learning as four interrelated strands: 1) Understanding scientific explanations, 2) generating scientific evidence, 3) reflecting on scientific knowledge, and 4) participating productively in science.

In 2012, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* was published by the National Research Council. This framework was a culmination of the previously mentioned works and addressed that true scientific learning only occurs when students' preconceptions are activated, they create a framework to hang their new knowledge on, students take control of their learning by setting goals, and students get to engage in the practices of science.

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas defines disciplinary core ideas as the content knowledge students should know after each grade level or class. Unlike previous science standards, the disciplinary core ideas focus on a smaller, more attainable number of concepts that will be cycled through repeatedly as a student gets older to allow students to build upon prior knowledge and experiences.

Cross-cutting concepts are ideas that pervade science and show up repeatedly. Teaching with cross-cutting concepts allows students to learn that chemistry, biology, physics, and earth science are not isolated bodies of knowledge, but instead, that science is a massive, interconnected discipline. Cross-cutting concepts allow for an integration among the branches of science creating an even larger, overarching framework.

The science and engineering practices are eight practices built from the ideas presented in *How Students Learn: Science in the Classroom*, *Ready, Set, Science!* and *Taking Science to School.* These eight practices are summarized in Figure 1. In response to *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* and a call for new science standards, the Next Generation Science Standards (NGSS) were published in 2013, and in 2014 Oklahoma released the Oklahoma Academic Science Standards (OASS) aligned very closely to the NGSS. Of the eight practices outlined in the NGSS and OASS, I chose to utilize planning and carrying out investigations in this project because I felt like it would be a useful instructional technique for the physical science standards I would be covering in the spring semester. Also, planning and carrying out investigations integrates many other science and engineering practices. To plan and carry out an investigation, students have to be able to define a problem, analyze and interpret data, and communicate information as part of the process.

NGSS Science and Engineering Practices	Ask questions and define problems	Plan and carry out investigations	Use mathematics and computational thinking	Obtain, evaluate, and communicate information
	Develop and use models	Analyze and interpret data	Construct explanations and design solutions	Engage in argument from evidence

Figure 1: The eight science and engineering practices outlined in the NGSS and OASS.

Science education research now recognizes students best learn by practicing science in the same way scientists and engineers would. Rather than focusing strictly on scientific content, or the facts, students best learn science by being engaged in practicing science. In this way they learn the "how" or "why" behind the facts to give students a better understanding of scientific concepts, promote scientific literacy, and give students the skills necessary to solve authentic problems and explain phenomena. Scientific facts and content knowledge are still a part of the curriculum but are only the basis for a much bigger picture.

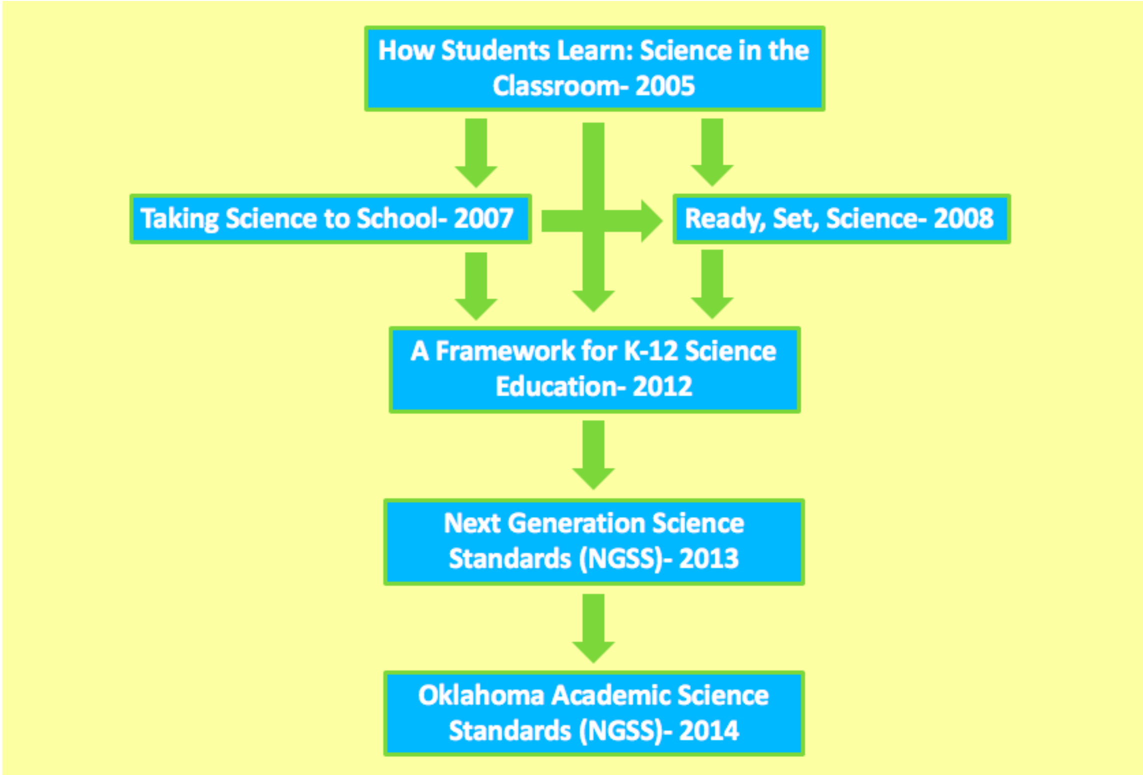

Figure 2: A summary of the research publications that led to the creation of the NGSS and OASS. Arrows in the diagram show connections and the flow of ideas between research publications and standards.

Part of this bigger picture comes from understanding how the process of science works and the process by which scientific facts are uncovered. Scientists and engineers plan and carry out scientific investigations in laboratories, in the field, or in combination. They may gather evidence individually, but often work collaboratively with other researchers. For scientists, investigations are systematic methods of gathering specific data within the bounds of set parameters. Data serves as a basis for evidence to support a claim. For engineers, investigations are often tests of designs or solutions to problems.

Engineering investigations involve modifying designs and solutions by applying scientific knowledge to increase benefits while decreasing risks (NRC 2012)

Classroom investigations allow students to actively participate in the scientific and engineering process to give them a better understanding of how facts and solutions to problems are obtained. When students plan and carry out investigations they are required to figure out what kind of information needs to be collected to address their questions about a phenomenon or design. They are also required to decide how to systematically collect and record data (Schwarz et al. 2017) and may be limited by parameters such as cost and provided materials.

The practice of planning and carrying out investigations is fundamental to students' understanding of science because investigations integrate many other science and engineering practices (Schwarz et al. 2017). To plan an investigation, students must make decisions about a guiding question or goal. They must utilize scientific models to put guiding questions into context. After investigating, students must analyze and interpret data and use that data to form an explanation or change an incorrect explanation. Lastly, students must communicate their ideas with others. All of these practices enhance students' understanding of science as a massive, interconnected enterprise and help them learn how scientific knowledge is obtained.

All forms of scientific knowledge including theories, explanations, facts, and models are judged in part by how consistent they are with real-world observations (Schwarz et al. 2017). Even young students can learn a significant amount by observing the world around them and asking questions. Incorporating effective investigations in classrooms fosters a scientific mindset in students and helps build critical thinking skills that students will take far beyond K-12 classrooms.

Research Questions

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (K-12 Framework) and the subsequent NGSS/OASS seek to address concerns about scientific literacy and critical thinking skills in the American public. The K-12 Framework and NGSS/OASS emphasize that students best develop scientific literacy and critical thinking skills through active engagement in practices that mirror the scientific process, including planning and carrying out scientific investigations (NRC 2012). Few, if any, studies have been conducted to determine whether or not this effect carries over to student content knowledge and perceptions of science.

Science educators recognize classroom investigations are one of the most impactful forms of teaching scientific concepts (Bills 2013). A large and growing body of research and publications provide an idealized notion of what planning and carrying out investigations should look like in K-12 classrooms (Bills 2013, Bautista 2017, Olsen et al. 2018), but fail to provide descriptive results about the effects of implementation.

Based on the problems outlined above, two research questions were developed for this project:

1. Assess what effect developing and implementing a curriculum that emphasizes planning and carrying out scientific investigations has upon student content knowledge growth.

2. Assess what effect developing and implementing a curriculum that emphasizes planning and carrying out scientific investigations has upon student attitudes toward science.

METHODS

Sample

A sample was drawn from physical science students at a suburban central Oklahoma high school. The class was an on-level, non-honors course. Students at this school are predominantly white, affluent, and traditionally do well on standardized tests compared to state and national averages. The average ACT score for the school during the study year was 22.2, which was above the national average. Only 9.8% of students enrolled at the school were eligible for free or reduced lunch. 55 students participated in the study. Of those 55, 34 were male, 21 were female, and three students were on an individualized education plan (IEP). Study participants were 80% Caucasian, 7% Black, 9% Hispanic, and 4% other. Students were primarily freshmen, aged 14-16. I used my own students for this study. By only using my own students as opposed to multiple instructors I eliminated a great deal of confounding variables such as age and experience. By using my own students, I was able to create and implement a treatment/non-treatment model that eliminated instructor effect.

Study design

Experimental design assessed whether a cause and effect relationship existed between the type of curriculum implemented and student outcomes. A total of three control and three experimental (treatment) units were taught over the course of the spring semester, beginning with a treatment unit. I chose to first implement a treatment unit to continue a sensible storyline of subject matter and maintain cohesiveness between the content knowledge students learned at the end of the fall semester. Both treatment and control units lasted 15 class periods on average. All units were designed to meet the NGSS and OASS.

Curriculum

During control units students started by taking a multiple-choice pretest. After students took their pretests I would use direct instruction to communicate the information students needed to know. I used lectures, vocabulary assignments, basic practice worksheets, guided notes, and text-book work. At the end of the unit students took a multiple-choice post-test and completed a survey about their attitudes towards science. Control units were not phenomenon based.

For treatment units, students would also begin with a multiple-choice pre-test. After that, I would present students with a real-world phenomenon or problem. For example, in one unit, I provided students with information about the number of children who are killed each year after being left in hot cars. I showed them data about the outdoor temperatures on the days of certain deaths, and I asked "how is it possible for a car to get so hot that it can kill a person on a 75-degree day?" I used this question to guide their thinking throughout the unit without ever giving them the answer outright. After being presented with the phenomenon or problem I gave students certain parameters for building a solar oven from household materials. Students worked in small groups to research solar ovens and associated concepts, come up with a design, justify their designs based on their research, build their designs, test their designs, analyze their data, and communicate their results. After the investigation, students were asked to explain the original guiding question based on what they learned, referencing back to their solar oven data. Students then took a multiple-choice post-test and completed a survey about their attitudes towards science. Treatment units included students learning about thermodynamics through building and testing solar ovens, learning about Newton's laws through building and testing an egg drop structure, and learning about electromagnetism through building and testing electromagnets.

There was a measurable difference between treatment and control units based on the NGSS EQuIP Rubric Lesson Screener. This is a tool teachers can use to ensure alignment to all parts of the NGSS. Of the six domains outlined in the tool, treatment units provided evidence for alignment for five of the six. Because control units did not include or inadequately included scientific practices, they aligned to a maximum of two of six domains.

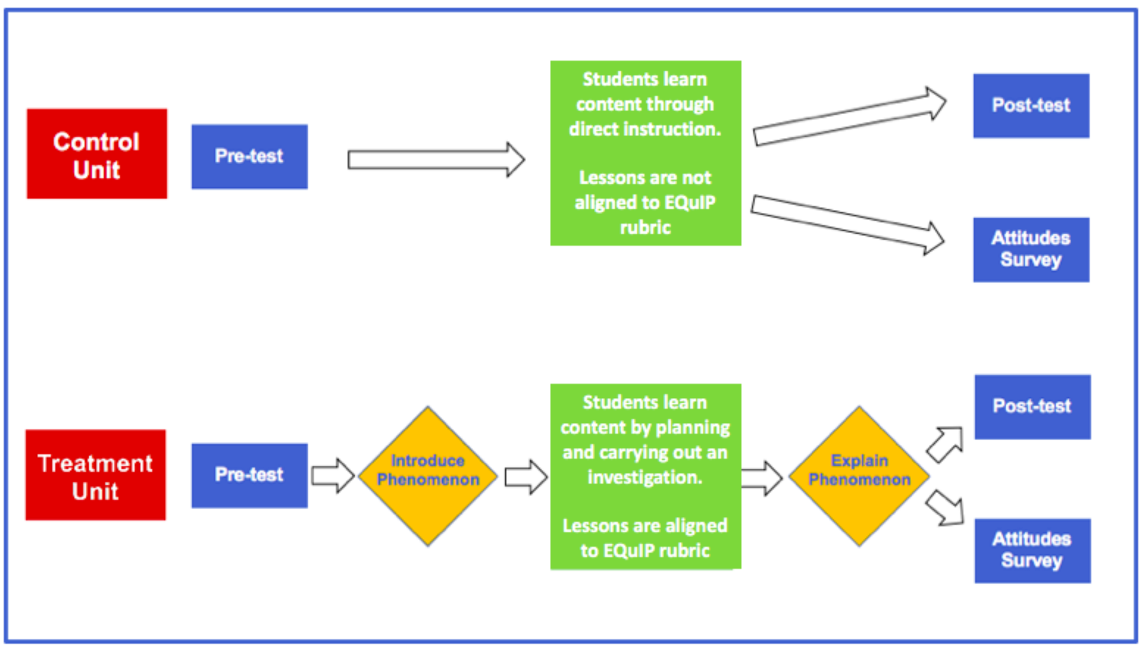

Figure. 3: Summary of Control and Treatment Unit Design

Tools for measurement

Pre and post-tests were administered for each unit to measure changes in student content knowledge during the unit. Before beginning the study, I developed these summative pre-assessments and post-assessments for each unit to measure changes in student content knowledge throughout each unit. Each assessment consisted of 16-35 multiple-choice questions designed to assess content knowledge specific to each unit. All assessments were aligned to the following depth of knowledge (DOK) framework:

- 15-25% DOK question-level one
- 55-65% DOK question-level two
- 15-25% DOK question-level three

At the end of each unit, I administered a student survey to measure student attitudes towards science. The survey consisted of 15 items designed to measure overall interest in science and the perceived importance of scientific knowledge. For each item, students were asked to rank their perceptions of the prompt from “strongly agree” to “strongly disagree”. The survey instrument was adapted and shortened from the Behaviors, Related Attitudes, and Intentions toward Science or BRAINS Survey, a testing instrument that has been psychometrically validated by researchers at the University of North Dakota (Summers and Abd-El-Khalick, 2018). The same survey was used at the conclusion of each unit. There is evidence in the literature that the experiences students have in K-12 science classes influence students’ decisions to pursue futures in STEM, so I was interested in seeing if a curriculum change would have any effect on how students felt about science as a whole (Shumow and Schmidt 2015).

Data analysis

All statistical analysis was run using IBM SPSS Statistics (Pallant 2007). Mixed methods ANOVA compared changes between pre-assessment and post-assessment scores (content knowledge growth) for treatment and control units. Mixed design addresses two factors: treatment vs. control, and time (pre-tests vs. post-tests). A mixed-methods ANOVA compared the means of these two factors. Pre-assessment and post-assessment data met the assumptions for mixed-methods ANOVA. Paired samples t-tests compared attitude surveys between treatment and control units. Survey data met the assumptions for paired samples t-tests.

RESULTS

Students experienced content knowledge growth between all pre-assessment and post-assessments, however, there was no significant difference between content knowledge growth in control units compared to treatment units (Figure 4) ($p=0.264$). In fact, students experienced an increase in average growth (Figure 5) during control units (pre-test average score- 47.69%, post-test average score- 82.72%) compared to treatment units (pre-test average score- 52.91%, post-test average score- 74.17%), however this increase was not statistically significant ($p= 0.264$). Though established research (NRC 2012) suggests planning and carrying out investigations can have a significant impact on students' understanding of the scientific process, pre and post-assessment data show that the impact was not the same for content knowledge.

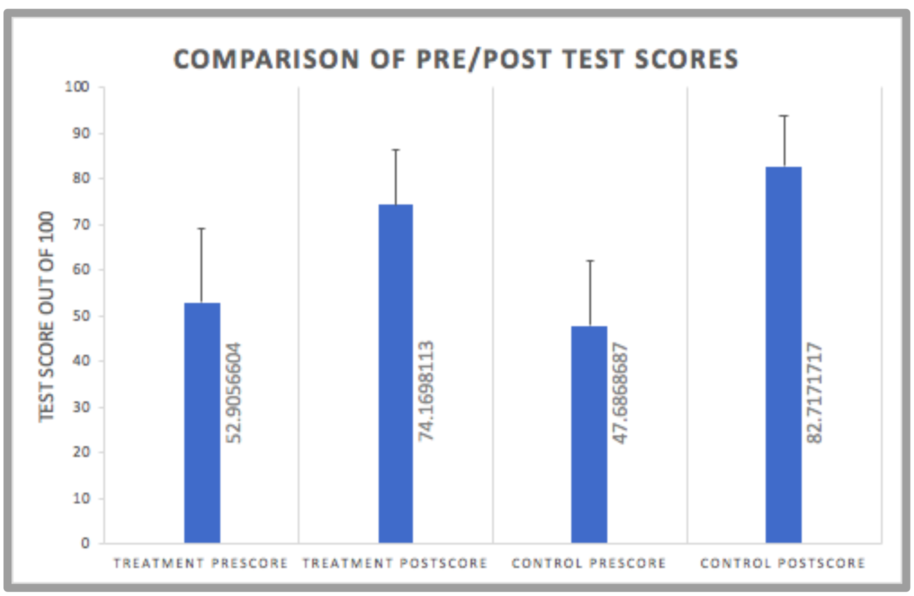

Figure 4: Comparison of test scores (growth) between pre-tests and post-tests for treatment and control units.

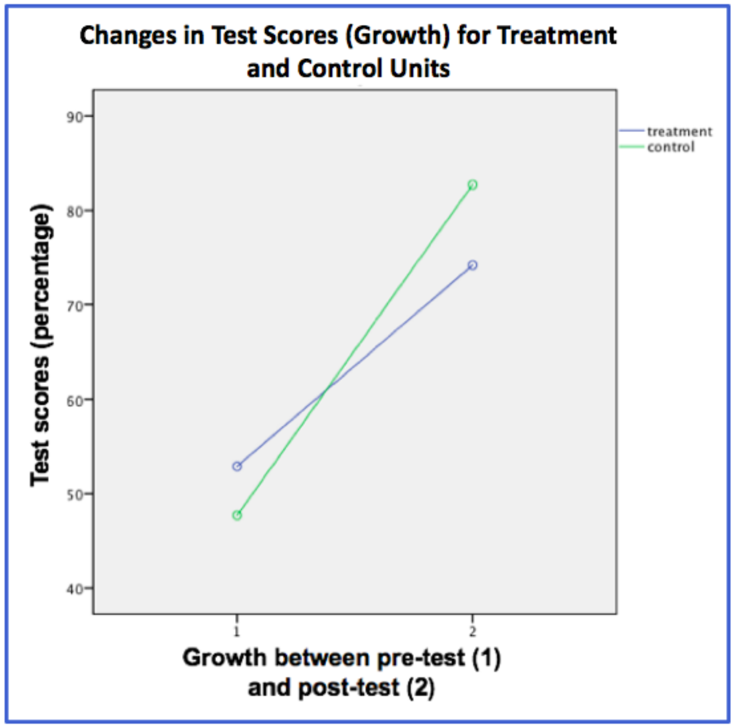

Figure 5: Changes in test scores (growth) between pre-tests and post-tests for treatment and control units. The graph shows the difference in the rate of increase between groups from pre and post-tests. While a difference is shown, the difference was not statistically significant (p= 0.264).

There was also no significant difference in students' attitudes toward science for the control curriculum compared to the treatment curriculum (Figure 6) (p=0.178). Mean student survey scores show a slight increase during control units. Mean scores increased by 2% during control units, but the effect was statistically insignificant (Table 2).

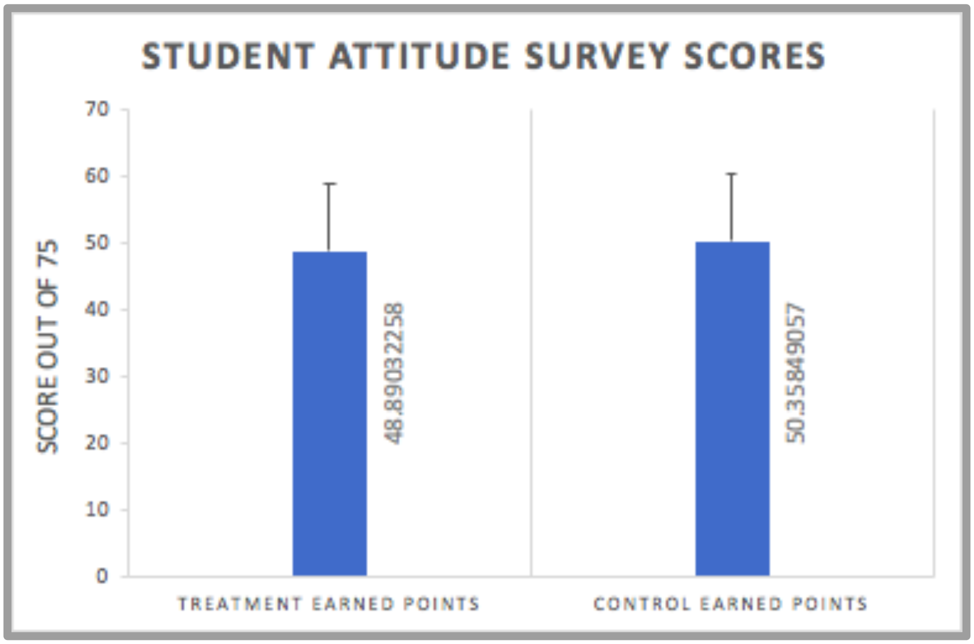

Figure 6: Comparison of attitude scores between control and treatment units.

	Mean score	Standard deviation
Treatment 1	48.5	8.85
Treatment 2	49.4	9.95
Treatment 3	48.8	11.7
Treatment totals	48.9	10.1
Control 1	49.7	8.92
Control 2	49.8	11.0
Control 3	51.6	9.90
Control totals	50.4	9.96

Table 2: Student attitudes towards science survey data comparing individual units.

The highest score possible on the survey is a 75.

DISCUSSION

Educational strategies presented in *A Framework for K-12 Science Education* move away from teaching isolated facts and move towards teaching the facts through engagement in scientific practices within a cross-disciplinary context (Krajcik et al. 2014, NRC 2007). Teaching and Learning in this way allows students to create knowledge frameworks for themselves to hang information on in a way that they may retain the information long term as opposed to memorizing and quickly forgetting isolated facts. This ideally leads to an increase in scientific literacy, an increase in critical consumption of information, and a better understanding of the scientific process. This overarching scientific understanding is what society needs in the next generation of STEM workers and non-STEM workers alike (NRC 2007).

A major component of the scientific practice is planning and carrying out a systematic investigation. The term *investigation* has two meanings within science: one for scientists and one for engineers. For scientists, investigations require revising and developing new theories or working from existing theories or explanations to identify what data needs to be recorded, what variables should be selected, and what variables should be controlled for, then coming up with a systematic way to collect relevant data. For engineers, investigations are used to gain essential data for design criteria or specific parameters to test a design. Like scientists, engineers must select relevant variables, decide how they will be measured, and collect data for analysis. Engineering investigations help identify how effective a design may be under certain parameters or conditions. Students in this study conducted investigations based on the engineering definition of investigation.

There is evidence that the treatment curriculum did contribute to student learning, just not necessarily more than traditional methods of teaching, and that is important to note. This means educators can focus on the practices and still successfully get the content across to students. Established research stresses the importance of using a curriculum that focuses on scientific practices to enhance student understanding of science as an enterprise, yet teachers are apprehensive about doing it for a variety of reasons (K-12 Framework, NRC 2012). One reason is the fear of running out of time to cover content if you spend time focusing on the practices. My research shows you can do both at the same time, and students still show content knowledge gains.

The results of this study demonstrated that developing and implementing a curriculum that emphasizes planning and carrying out scientific investigations has no statistically significant effect on student content knowledge growth. In fact, the results demonstrated that students did slightly better on unit exams and showed an increase in growth (change between pre-test and post-test) during control units compared to treatment units, although that difference was not significantly significant. This is likely because students are more familiar with the curriculum format of control units. Control units utilized traditional lessons such as direct instruction, vocabulary, lectures, guided notes, confirmatory labs, and using the textbook to find answers. Students in this study are very familiar with learning science this way. Students are less familiar with explaining phenomena and learning through guided inquiry as curriculums that include these concepts are relatively new. Students seemed to have found it difficult to extrapolate information on their own as they designed and carried out their own investigations. Students in the study sample are used to having the information presented to them directly, however, if they were taught science in this new way from a young age results may have been different.

Results indicate that utilizing this new process doesn't have a negative or positive impact on student learning. Students did not struggle to understand the material while focusing on the science process any more than they did during control units. This supports the idea that science in the modern classroom can indeed be taught just as effectively without direct instruction, lectures, vocab, worksheets, and other traditional methods of teaching.

A focus on planning and carrying out investigations also produced no significant difference in student attitudes toward science as reported in science attitude surveys. This may have been the result of the questions on the survey instrument. The survey gave broad statements such as "I would enjoy working in a science-related career" and "I will study science if I get into a university", not statements about individual lessons and class activities. The short time spent in each unit may have not been enough to change students' broad feelings about science as a whole. Better survey questions would probe specific insights into students' feelings towards class activities like "I prefer hands-on activities to paper assignments" or "I enjoy designing lab experiments". Interview based research instruments may have worked better to accurately identify how students felt about science as a result of the curriculum change.

In addition to the study limitations listed above, other limitations include having a small n value of 55 study participants. Those participants were relatively homogenous from a demographic standpoint. In addition, some topics had previously been covered in earlier classes while others had not. For example, students came to my classroom already knowing quite a bit about Newton's laws, but they knew almost nothing about electricity and magnetism. This may have had an effect on their pretest scores, which would have had an effect on content knowledge growth.

I know now for future research that the sensitivity of the tests used to determine content knowledge and attitudes may not have been adequate for picking up changes for understanding how science works. I was teaching content in a new way, and I'm not sure my instruments were capable of getting to the conceptual understandings that I found when I was talking to students during the unit. By changing the curriculum, I may have in fact altered their content knowledge and scientific understanding in ways a multiple-choice test or broad survey is unable to pick up.

I was relatively new to teaching science using the new curriculum. It is possible that this may have affected the results If my newness to this teaching method had an effect on results, I believe it would have decreased the effect on content knowledge and student attitudes. I might have seen more of an effect on content knowledge and student attitudes if I was a seasoned expert at teaching this new curriculum.

Future Research

While the results of my study demonstrated that learning through scientific practice is challenging to students, existing research suggests learning science this way enhances students' scientific literacy and gives students the tools they need to solve complex scientific problems and explain scientific phenomena (NRC 2007). Future research should assess changes in students' capacity to scientifically reason using instruments separate from those that measure content knowledge. Assessment tools should measure student's understanding of scientific literacy and the scientific processes being taught, not strictly content knowledge. Future research should also consider whether effects on the implementation of a curriculum that focuses on scientific investigation are equal for all groups of students, including those in advanced classes and those from underrepresented groups.

Future research should also assess the long-term effects of the implementation of a curriculum that focuses on scientific investigation. While the results of my study did not show an increase in immediate content knowledge growth, it would be interesting to assess what content knowledge students retain six months out from the study, a year out, or more. Future research should also assess what effect long term use of scientific practice-based curriculum has on student attitudes toward science. It is unlikely that a single intervention is capable of substantially altering a student's perception of science, so future research will need to utilize a longitudinal study design to assess changes over longer periods of time.

Future research could also assess what effect this curriculum has on a student's capacity to answer questions at the different DOK levels. I do not think a significant difference would be present in DOK level one, as DOK level one questions are lower-level questions including vocabulary and identification. I also don't think a significant difference would be present in DOK level two because the largest portion of the tests given in this study were level two questions and no effect was shown. If a DOK-dependent effect was present, I think it would have most likely shown up in the DOK level three questions that ask students to scientifically reason and apply knowledge to new situations.

REFERENCES

Bautista, J. 2017. *The Paper Airplane Challenge*. Science and Children 55: 82-87.

Bills. P. 2013. *Teaching Long-term Science Investigations: a Matter of Talk, Text, and Time.* Michigan State University.

Effect Size Calculator for T-Test. (n.d.). Retrieved March 22, 2020, from https://www.socscistatistics.com/effectsize/default3.aspx

Krajcik, J., Codere, S., Dahsah, C., Bayer, R., Mun, K. 2014. *Planning Instruction to Meet the Intent of the Next Generation Science Standards.* Journal of Science Teacher Education 25: 157-175.

National Research Council. 2005. *How Students Learn: Science in the Classroom*. Washington, DC: The National Academies Press.

National Research Council. 2007. *Taking Science to School: Learning and Teaching Science in Grades K-8.* Washington, DC: The National Academies Press.

National Research Council. 2008. *Ready, Set, SCIENCE!: Putting Research to Work in K-8 Science Classrooms*. Washington, DC: The National Academies Press.

National Research Council. 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.

Olsen, E., Tofel-Grehl, C., Ball, D. 2018. *The Temperature-Sensing Lunchbox*. Science Scope 42: 47-52.

Pallant, J. 2007. *SPSS Survival Manual: a Step by Step Guide to Data Analysis Using SPSS for Windows* (Third edition. ed.). Maidenhead Open University Press.

Schwarz, C., Passmore, C., Reiser, B. 2017. *Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices*. NSTA Press.

Shumow, L., & Schmidt, J. (2015). Teaching the Value of Science. *Educational Leadership, 72*(4), 62-67.

Summers, R., and Abd-El-Khalick, F. 2018. Development and validation of an instrument to assess student attitudes toward science across grades 5 through 10. *Journal of Research in Science Teaching, 55*: 172-205.

PROJECT CONCLUSION

Through my scientific research with Dr. Creecy and Dr. Bass I learned how to take a real-word problem, conduct literary research, write the steps based on that research to find a solution, conduct those steps, and communicate results. It turns out that "oh gosh I don't know what to do" feeling isn't so bad. In fact, it's an integral part of the scientific process. In turn, I took my new skillset and all that I had learned through my research experience to my high school classroom.

Despite the fact that the microbiology analysis I conducted with Dr. Creecy and Dr. Bass was relatively crude, the impact of the experience of getting to work in a lab, having to plan an investigation, and carrying out those plans was enormous. There is no substitute for getting the hands-on experience of a scientist. I learned how to integrate the skills I learned from my undergraduate science courses beyond strictly teaching the content. Conducting my own investigation illuminated the fact that all my previous science courses are parts of a larger enterprise, and that while the concepts may vary, the scientific skills and practices are cohesive across all scientific disciplines. These practices include determining a problem or coming up with a question, researching through the peer-reviewed literature to extrapolate useful information, planning the steps of an investigation, analyzing and interpreting data using computer analysis and mathematics, and being able to effectively communicate that information in such a way that evokes societal change.

Before this experience I was teaching lab science in the same way that I was taught most lab science: Teach content, then conduct a lab with predetermined steps to reinforce that content. While this method has some merit, it can't compare to planning and carrying out your own investigation from scratch to not only reinforce content, but scientific practices as well. Having my experience in Dr. Creecy's lab put me in a unique position to be better able to teach these skills to students. It's one thing to read about what scientists do and the challenges they face, it is another to dive in and experience it firsthand. As a result of what I learned, I think undergraduate research experiences should be a required part of science teacher preparation programs. I believe this shift in degree requirements would produce graduates more capable of providing their K-12 students with authentic scientific experiences in the classroom.

I'm also now in a much better position to assess the effects of curriculum changes in my classroom as a result of my work with Dr. Nelson and Dr. Allan. I see my classroom in an entirely different way as a result of this study. My classroom isn't just the place where I teach, it is also my educational research lab.

Even though my data did not show a significant difference between content knowledge growth between treatments, I will continue to teach in this way in the future. My students still learned scientific content, just not necessarily more than they learned in traditional units. During treatment units students repeatedly expressed that they preferred the more "hands-on" units and felt like they got more out of them. They enjoyed working in groups, moving around, going outside, and having more agency in their learning. I observed an increase in student willingness to participate in class during treatment units, although this was not assessed by my research design. I observed students who regularly acted bored by the class excited to take part in treatment activities. For these reasons I will continue to implement the research skills I learned through my scientific and educational research into my classroom and provide my students with unique opportunities to engage in the process of science. As a teacher I look at more than exam grades to determine instructional effectiveness. It was obvious to me that this “new” method of teaching science had a direct impact on my students, even though my research did not explicitly measure things like behavior, motivation, and communication skills.